STUDY OF THE TEMPERATURE DISTRIBUTION IN THE LININGS OF HORIZONTAL CONVERTERS USED IN NONFERROUS METALLURGY

V. V. Slovikovskii[1] and A. V. Gulyaeva[1]

Translated from *Novye Ogneupory*, No. 12, pp. 25 – 28, December, 2012.

Original article submitted October 19, 2012.

A study is made of the temperature distribution in lined horizontal converters used to make nickel and copper. The temperature distribution is studied for different regimes of converter operation in order to investigate the thermal conductivity of refractory linings composed of different refractory products. Thermal conductivity is determined for linings in their initial state and after their impregnation with copper-nickel mattes. The study results can be used to estimate the temperature of a lining through its cross section and thus calculate the value of lining thickness at which different mortars used with the lining will begin to sinter. To prevent fracture of the lining by thermal stresses, it must be heated by burners to keep its temperature from descending below 700 – 800°C (the beginning of solidification of the matte). Otherwise, 40 – 80 mm of the lining material will spall.

Keywords: spalling of refractory products, roasting temperature, matte, thickness of matte-impregnated refractory, physical model, heat-conducting mortars, protective coatings, SHS-mortar.

The lining of the horizontal converters used in nonferrous metallurgy is a complex multilayered body that undergoes periodic steady and local thermal shock as a result of its heating and cooling during the conversion operation. These are integrated pauses during which individual portions of a matte are processed in reactions that have a net exothermic effect. Here, FeS is oxidized to FeO and SiO_2 is fluxed to form a high-iron fayalite slag that is discharged. Then the next fresh batch of matte is charged into the converter. These processes entail stoppage of the converter to cold-charge fluxing materials and metal wastes.

In addition to the thermal shocks that the entire lining experiences, individual parts of the lining are subjected to local (and fairly substantial) thermal shocks. Foremost among these parts is the slag belt and the zones of the lining above and below the tuyeres. The temperatures in these regions are significantly lower than in the rest of the lining during the conversion process thanks to the cooling effect of the air that is sent into the furnace's working space under a pressure of 3 – 6 at (0.3 – 0.6 MPa). The air is needed to convert iron sulfide to iron oxide. During the periodic stoppages of the converter, involving cessation of the air feed and removal of the melt from the tuyere belt, the parts of the lining just mentioned undergo rapid heating due to thermal radiation from the surface of the melt and heat conduction from the other, hotter parts of the lining. The subsequent restart of the air feed leads to rapid cooling of the heated tuyere belt (the temperature of the process air that is injected is 20°C).

[1] Ural Federal University, Ekaterinburg, Russia.

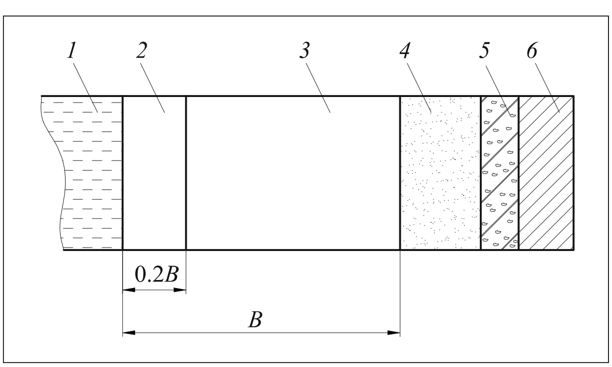

Fig. 1. Sketch of the physical model of the converter lining: *1*) melt; *2*) the part of the lining that is impregnated with the slag-matte melt; *3*) non-impregnated part of the lining; *4*) filler composed of powdered magnesia; *5*) layer of asbestos; *6*) metal shell.

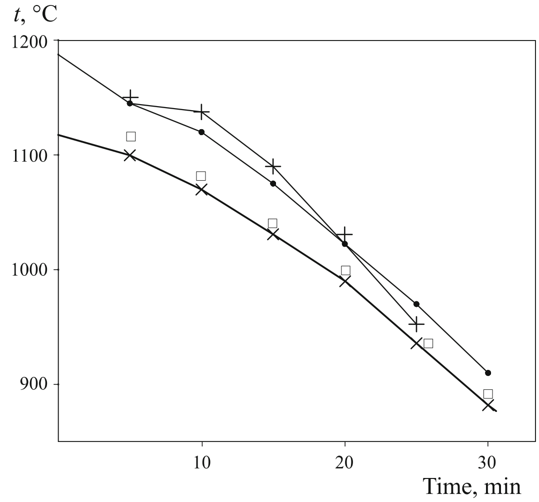

Fig. 2. Temperature t of the working surface of a converter at the KMK during cessation of the air feed. Results of measurements of temperature on converters 2 (+) and 3 (×) and data calculated for converters 2 (●) and 3 (□).

Destruction of the lining of the furnaces used in nonferrous metallurgy is also accelerated by the fact that — in contrast to experiences with the use of vertical converters in ferrous metallurgy — the lining of horizontal converters is usually not preheated before startup of the furnace. The lining is heated by feeding liquid slag into the "cold" working part of the converter. Introduction of the slag is followed by charging of working portions of the matte.

TABLE 1. Change in the Temperature of the Working (Flame-Covered) Surface of the Tuyere Belt of the Lining with Stoppage of the Copper Converter.

Converter	Duration of furnace stoppage, min	Temperature of working surface of lining, °C
2	0	1190
2	5	1150
2	10	1140
2	15	1090
2	25	950
3	0	1120
3	10	1070
3	15	1030
3	20	990
3	22*	980
3	25	860
3	35**	820
3	40***	850

* Metal wastes are charged into the converter.
** Metal wastes are added to the converter.
*** The matte is poured into a ladle.

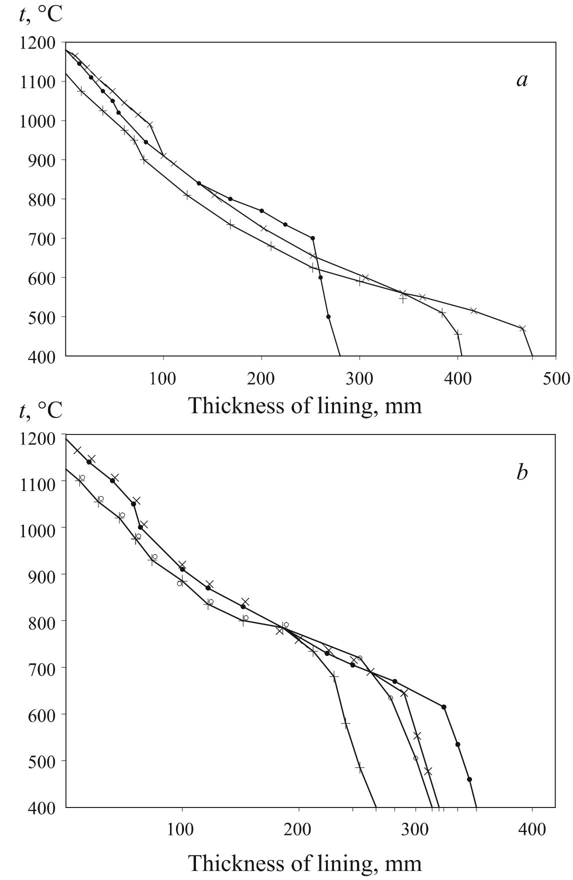

Fig. 3. Temperature distribution through the thickness of the lining of converters at the UNK (a) and KMK (b) during steady-state operation: a) results of measurements of temperature on converters 1 (+), 2 (●), and 5 (×); b) results of measurements of temperature on converters 2 (●) and 3 (+), calculated data for converters 2 (×) and 3 (○); maximum service temperature of the lining 1190°C in converter 2 and 1120°C in converter 3 with a lining thickness of 400 and 310 mm for the measurements and 370 and 360 mm for the calculations, respectively.

In addition to thermal shocks, the lining of horizontal converters is subjected to the aggressive action of the high-iron fayalite slag. The matte-slag melt penetrates the lining to a fairly significant depth (up to 40% of the length of the refractory), which results in changes to the thermophysical characteristics of the different zones of refractory products. Such penetration often leads to spalling of the refractory along the joints between these zones parallel to the lining's working surface.

In light of the above, two mutually exclusive approaches are now being taken to increasing the durability of converter linings. The first approach requires that heat be rapidly removed from the furnace's working space in order to lower the temperature in the melt-lining contact region and form a slag crust on the lining's surface. It has been proposed that this be done by installing a high-heat-conducting filling material between the lining and the furnace shell, installing cooling pipes between the lining and the shell, or using other measures [1 – 4]. These changes would increase the temperature gradient. In the second approach, to alleviate spalling of the lining the temperature gradient in it is reduced by placing a heat-insulating filler with a thermal conductivity $\lambda = 0.23$ W(m·deg) between the furnace shell and the refractory and inserting several layers of sheet asbestos between the shell and the "cold" part of the lining. However, this approach raises the temperature at the melt-refractory interface and increases the danger of destruction of the refractory lining due to chemical wear by the highly aggressive slag and spalling of the lining as a result of its deeper penetration by the matte.

The first method of increasing the life of the lining would appear to be preferable, but the literature data shows that there has not been enough study of the temperature distribution over the cross section of linings. Thus, it is impossi-

TABLE 2. Thermal Conductivity, W/(m·deg), of Refractories in Relation to Temperature

Temperature, °C	Thermal conductivity λ	Average thermal conductivity λ_{av}
Initial KhP refractory		
200	1.24 – 1.35	1.295 ± 0.055
400	1.84 – 1.93	1.829 ± 0.045
600	1.8 – 2.03	1.92 ± 0.12
800	1.6 – 1.6	1.6 ± 0
KhP refractory with copper matte		
150	2.0 – 2.37	2.185 ± 0.19
200	2.06 – 2.23	2.15 ± 0.09
300	2.2 – 2.21	2.21 ± 0.05
400	2.2 – 2.25	2.23 ± 0.025
500	2.08 – 2.15	2.12 ± 0.035
600	2.2 – 2.25	2.02 ± 0.01
800	2.08 – 2.15	1.87 ± 0.05
KhP refractory with nickel matte		
200	2.68 – 2.75	2.72 ± 0.036
300	2.65 – 2.72	2.69 ± 0.035
400	2.6 – 2.62	2.61 ± 0.01
500	2.49 – 2.47	2.48 ± 0.01
600	2.34 – 2.37	2.38 ± 0.015
800	2.24 – 2.27	2.26 ± 0.015
Initial KhPT refractory		
200	2.1 – 2.22	2.16 ± 0.06
300	2.63 – 2.64	2.64 ± 0.005
500	2.26 – 2.52	2.39 ± 0.013
700	1.65 – 1.95	1.8 ± 0.15
800	1.66 – 1.66	1.66 ± 0
KhPT refractory with copper matte		
200	3.72 – 3.77	3.75 ± 0.025
300	3.64 – 3.75	3.7 ± 0.055
400	3.63 – 3.67	3.65 ± 0.02
500	3.41 – 3.48	3.45 ± 0.035
600	3.21 – 3.23	3.22 ± 0.015
KhPT refractory with nickel matte		
200	2.99 – 3.17	3.08 ± 0.09
300	3.08 – 3.16	3.12 ± 0.04
400	2.96 – 3.02	2.99 ± 0.03
500	2.79 – 2.81	2.8 ± 0.01
600	2.39 – 2.43	2.41 ± 0.02
800	2.23 – 2.29	2.26 ± 0.03
Initial PKhS refractory		
200	3.31 – 3.33	5.35 ± 0.02
300	3.80 – 3.81	3.81 ± 0.005
400	3.89 – 4.02	3.96 ± 0.065
500	3.83 – 3.93	3.88 ± 0.05
700	3.55 – 3.6	3.58 ± 0.025
800	3.38 – 3.68	3.53 ± 0.015
PKhS refractory with copper matte		
200	5.33 – 5.37	5.35 ± 0.02
300	5.22 – 5.39	5.31 ± 0.085
400	5.01 – 5.13	5.07 ± 0.06
500	4.82 – 4.86	4.84 ± 0.02
600	4.61 – 4.61	4.61 ± 0
800	4.19 – 4.2	4.2 ± 0.005
PKhS refractory with nickel matte		
200	4.95 – 5.03	4.99 ± 0.04
300	5.07 – 5.09	5.08 ± 0.01
400	5.02 – 5.042	5.02 ± 0
500	4.8 – 4.83	4.82 ± 0.015
700	4.41 – 4.42	4.42 ± 0.005
800	4.17 – 4.23	4.2 ± 0.003
Initial PKhPPP refractory		
200	3.00 – 3.14	3.07 ± 0.07
300	3.66 – 3.81	3.74 ± 0.075
500	3.61 – 3.67	3.64 ± 0.03
700	3.28 – 3.31	3.3 ± 0.015
800	2.59 – 2.98	2.79 ± 0.195
PKhPPP refractory with copper matte		
200	4.55 – 4.65	4.57 ± 0.05
300	4.32 – 4.38	4.35 ± 0.03
400	4.12 – 4.18	4.15 ± 0.03
500	3.91 – 3.96	3.94 ± 0.025
600	3.69 – 3.71	3.7 ± 0.01
800	3.2 – 3.21	3.21 ± 0.005
PKhPPP refractory with nickel matte		
200	4.38 – 4.43 4.32 – 4.38	4.4 ± 0.025
300	4.34 – 4.4	4.37 ± 0.003
400	4.18 – 4.25	4.22 ± 0.035
500	3.69 – 3.74	3.72 ± 0.025
700	3.42 – 3.48	3.45 ± 0.03
800	3.14 – 3.28	3.21 ± 0.007

ble to either quantitatively or qualitatively evaluate the thermal stresses that develop in the lining during operation of the furnace and at the moments when furnace operation is briefly interrupted.

We conducted the study being discussed in this article in order to develop a physical model of the performance of the lining of a horizontal converter in the quasi-steady regime. The model is constructed from a heat-engineering perspective and the results obtained with it are compared to direct measurements of lining temperature, results obtained from the creation of a realistic model of furnace operation, and estimates of the stresses which develop over the lining's cross section. This approach will make it possible to find the best way to improve the durability of the lining through the adoption of appropriate measures. The objects of study were the linings of converters at the Kirovgrad Copper-Smelting Combine (KMK) and the Ufaleisk Nickel Combine (UNK).

The process of the removal of heat from the working space of horizontal converters can be regarded as heat transfer taking place between seven bodies (Fig. 1): the molten matte; the part of the lining that has been impregnated with the matte; the little-changed non-impregnated part of the lining; the filler between the "cold" part of the refractory and the furnace shell; the asbestos layers; the furnace shell; the air surrounding the furnace.

In light of this, we set forth the following objectives:

– create a physical model that describes the temperature distribution over the cross section of the lining of horizontal converters for a quasi-steady regime of operation of the furnace (the conversion regime); with a certain error, verify the accuracy of these calculated results by comparing them to temperature measurements made on actual furnaces;

– determine the critical time for stoppage of the converter without the air feed, i.e. the time which if exceeded would result in destruction of the lining by spalling due to cooling of the matte-slag melt.

The results of the temperature measurements are shown in Table 1. The results shown in Figs. 2 and 3 were substantiated by calculations performed on the basis of data that we obtained in accordance with the physical model of converter linings. For example, we determined the thermal conductivity of the initial magnesia-based refractories and the same refractories after they were impregnated by the matte (Table 2). In performing the calculations with allowance for the experimental data, we assumed that that 18 – 20% of the refractory is impregnated by the matte, the thickness of the magnesia-based filler is 180 – 200 mm, the total thickness of the asbestos sheets is 40 mm, and the thickness of the steel shell of the furnace is 20 mm. The values taken for the thermal conductivity of the asbestos and the steel are standard values and are not cited in this article.

Table 2 shows data for sintered KhP chromite-periclase refractories, heat-resistant KhPT chromite-periclase refractories, PKhS periclase-chromite roof refractories based on fused grains, and high-density PKhPPP refractories. It is apparent from Table 2 that an increase in temperature tends to be accompanied by a decrease in the thermal conductivity of the refractories both before and after impregnation with different mattes. An increase in the density of the refractory (PKhPPP) significantly changes the difference between the thermal conductivities of the refractory in its initial state and after impregnation with mattes. The method that was used to determine thermal conductivity was described in [7].

CONCLUSION

The results obtained from the above investigation can be used to determine the temperature of a lining over its cross section with a probability of 80 – 90%; calculate the value of lining thickness at which the lining's components or special additives in the refractory filler and the lining begin to sinter; determine the probability of occurrence of other processes in the filler, including "ignition" of SHS-mixtures [5].

The physical model that was developed can be used to test different high-conductivity additives for the filler, try different methods for accelerating the removal of heat from the "cold" part of the refractory, and test different mortars and gunites.

To prevent the fracture of a lining [6] due to thermal stresses when the converter is being stopped and the temperature of its lining is lower than 700 – 800°C (the beginning of solidification of the matte), it is recommended that the lining be heated by portable burners.

It is best to specially design the door or the cover of the discharge opening so as to reduce their temperature and lengthen the time that the converter can operate between repairs.

The results obtained here are making it possible to develop and assess the prospects of methods for improving the durability of horizontal converters used in nonferrous metallurgy.

REFERENCES

1. K. K. Strelov, *Technical Supervision of Refractories Production* [in Russian], Metallurgiya, Moscow (1970), pp. 15 – 42.
2. V. V. Slovikovskii, "Study of elastic mechanical and physico-chemical properties of refractory objects with the aim of predicting the endurance of a nonferrous metallurgy unit lining," *Refr. Ind. Ceram.*, **52**(5), 44 – 47 (2008).
3. V. V. Slovikovskii, "A method of reducing the thermal stresses in the lining of the tuyere belt in a nonferrous metallurgy converter," *Refr. Ind. Ceram.*, **49**(3), 216 – 218 (2008).
4. V. V. Slovikovskii, "Special bulk refractory with high thermal conductivity," *Novye Ogeneupory*, No. 4, 56 (2009).
5. V. V. Slovikovskii, S. V. Tyukov, and A. S. Kolina, "SHS-materials for repairs to the lining of furnaces used in nonferrous metallurgy," New Materials and Technologies: Proc. All-Russian Scientific-Technical Conference NTM. MATI, Moscow (2010).
6. V. K. Yakushev, Processes Involved in the Destruction of Furnace Linings [in Russian], Nauka, Alma-Ata (1987), pp. 203 – 210.
7. I. M. Rafalovich and I. A. Denisova, *Determination of the Thermophysical Properties of Metallic Materials* [in Russian], Metallurgiya, Moscow (1971).